Inflight Validation of the Calibration of Airborne Visible/Infrared Imaging Spectrometer in 1993

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ABSTRACT

To achieve the research objectives of the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS), the sensor calibration must be valid while AVIRIS is acquiring data from the airborne platform. The operational environment inside the aircraft differs significantly from that in the AVIRIS laboratory environment where the sensor is calibrated prior to and following each flight season. To independently validate the calibration of AVIRIS in the flight environment an inflight calibration experiment is conducted at least twice each flight season. Results for a calibration experiment held on the 26th of September 1993 are presented.

1.0 INTRODUCTION

AVIRIS measures the total up welling radiance from 390 to 2500 nm through 224 contiguous spectral channels. Images 11 km in width and up to 100 km in length are collected with 20 meter spatial resolution. Molecular absorption's and particle scattering signatures recorded in these spectra are used to pursue quantitative research in scientific disciplines investigating the Earth's surface and atmosphere. To achieve these research objectives, the calibration of AVIRIS must be valid while AVIRIS is acquiring data from the NASA ER-2 aircraft. At 20 km altitude in the Q-bay of the ER-2, the environment differs in terms of temperature, pressure, vibration and high frequency electromagnetic fields with respect to that in the laboratory where AVIRIS is calibrated. To validate the calibration and performance of AVIRIS in the flight environment; inflight calibration experiments are conducted each flight season (Conel, et al. 1988; Green, et al. 1988; Green et al, 1990; Green et al., 1992a). On the 26th of September 1993a calibration experiment was held on the dry lake bed at Lunar Lake, NV 120 km east of Tonopah, NV.

The inflight calibration experiment described was conducted by measuring the surface and atmosphere at a calibration target concurrently with AVIRIS airborne data acquisition. These in situ measurements were used to constrain a radiative transfer code and predict the up welling radiance at the AVIRIS sensor. This predicted radiance has been analyzed with the corresponding AVIRIS measured radiance to validate the calibration of AVIRIS in flight.

2.0 CALIBRATION EXPERIMENT MEASUREMENTS

2.1 Calibration Target

A calibration target was established at latitude 38.3973 longitude 115.9888 on a homogeneous portion of the dry lake bed surface of Lunar Lake, NV. This target consists of an area covering 40 by 200 m of the dry lake bed surface and corresponds an array to 2 by 10 AVIRIS spatial samples. At each end of the calibration target large blue tarps are placed to allow direct location of the target in the AVIRIS data based on the spectral absorption spectrum of the tarps.

2.2 Surface Reflectance

The spectral surface reflectance of the calibration target was measured during the hour preceding and following the AVIRIS overflight. During this period, forty reflectance measurements were acquired in a

' uniform distribution across the calibration target. The field spectrometer used exceeds the AVIRIS spectral resolution and range. The average spectrum for the calibration target together with estimated uncertainty is shown in Figure 1. The spectral reflectance of the calibration target at Lunar Lake is shown to be moderately bright and well characterized.

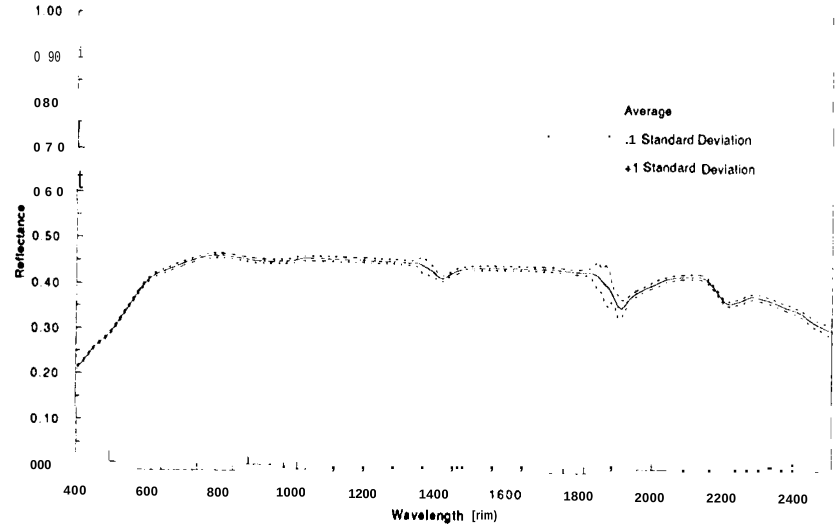

Figure 1. Average reflectance and uncertainty for the calibration target.

2.3 Atmospheric Optical Depths

To characterize the transmission and scattering properties of the atmosphere, a ten channel automated solar radiometer was used to track the sun from sunrise through local solar noon at the Lunar Lake, NV calibration target. The instantaneous total optical depths derived for the non water vapor channels from the radiometer data is given in Figure 2. These optical depths show the atmosphere to be clear and stable throughout the period of the calibration experiment,

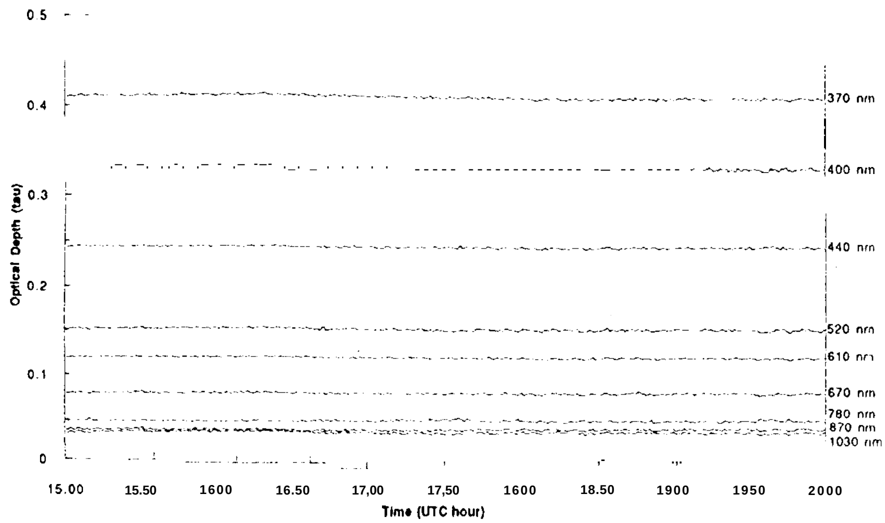

Figure 2. Instantaneous optical depths.

2.4 Atmospheric Water Vapor

Atmospheric water vapor at the calibration target is derived from the solar radiometer channel centered at 940 nm. Calculated instantaneous total column water vapor for this experiment is shown in Figure 3.

These data show an average of 4 mm of water vapor in the column with variation of several percent through the measurement sequence.

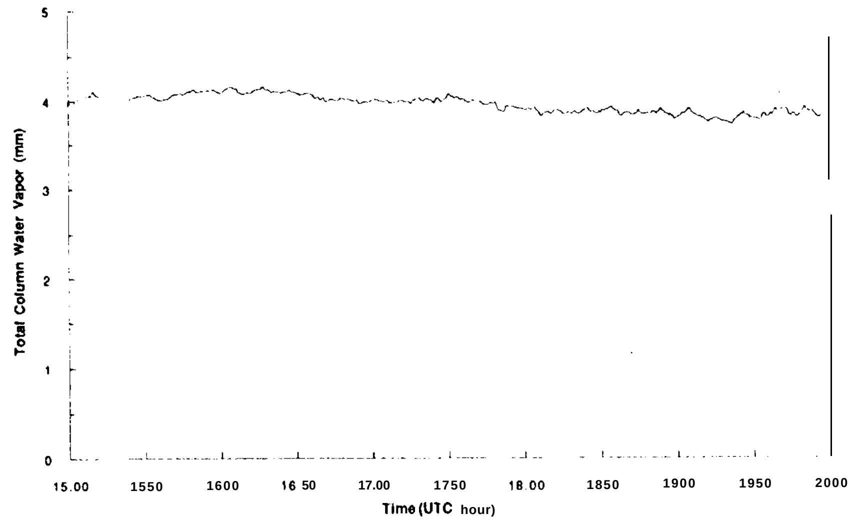

Figure 3. Instantaneous total column water vapor determined from the 940 nm channel of the solar radiometer.

3.0 MEASURED AND PREDICTED RADIANCE

3.1 AVIRIS Measured Radiance

Data acquired at the time of 17.733 UTC for the calibration target were extracted from the AVIRIS image for the 40 by 200 m area of the calibration target. The corresponding un-calibrated AVIRIS digitized numbers are shown in Figure 4 versus the 224 measured channels. These digitized numbers were spectrally and radiometrically calibrated based on the laboratory calibration measurements (Chrien et al., 1990), calibration algorithms (Green et al., 1991) and onboard calibrator (Green 1993). The calibrated spectrum, given as radiance versus wavelength of the calibration target is shown in Figure 5. Influence of atmospheric absorption, atmospheric scattering and surface spectral reflectance on the source solar irradiance are fully expressed in this calibrated spectrum of the upwelling radiance.

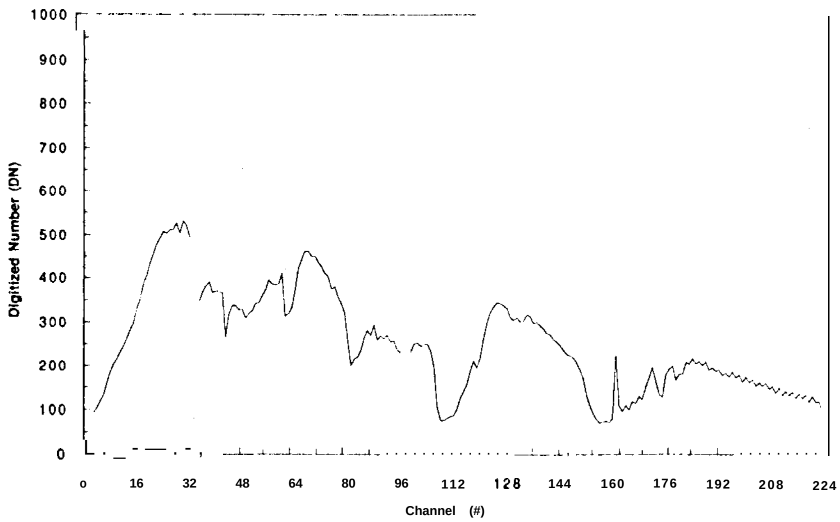

Figure 4. AVIRIS digitized numbers for the calibration target

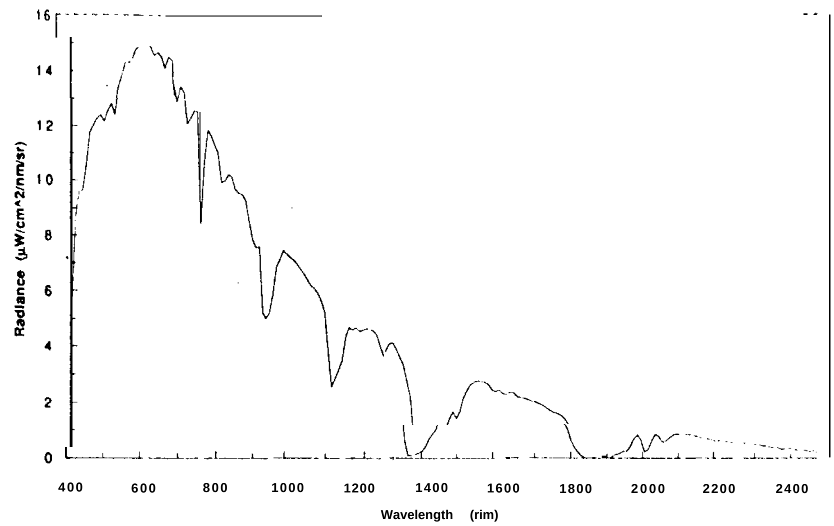

Figure 5. Laboratory calibration based AVIRIS upwelling spectral radiance,

3.2 Radiative Transfer Predicted Radiance

To predict the upwelling spectral radiance at AVIRIS, the MODTRAN radiative transfer code (Berk, et al. 1989) was used, MC) TRAN has been modified to allow: inclusion of the measured surface spectral reflectance, constraint of the atmospheric models with the measured optical depths, direct constraint of the atmospheric model with the measured water vapor amount and inclusion of an updated solar irradiance spectrum (Green and Gao 1993). This modified version of MODTRAN was constrained for parameters measured at the time of the AVIRIS overflight. For example, the measured and MODTRAN model optical depths are shown in Figure 6. Good agreement is shown between the measured and modeled values at wavelengths of overlap. The radiance spectrum predicted with MODTRAN for the calibration target is shown in Figure 7.

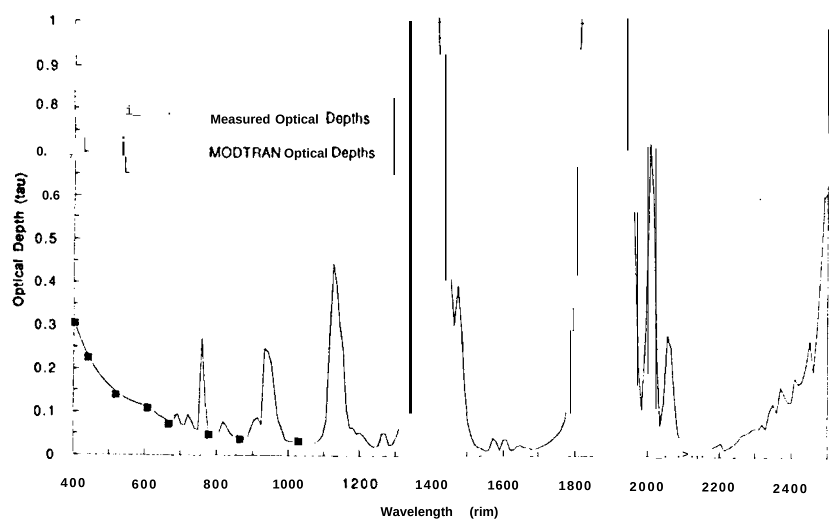

Figure 6. Measured and modeled optical depths for constraint of the radiative transfer code.

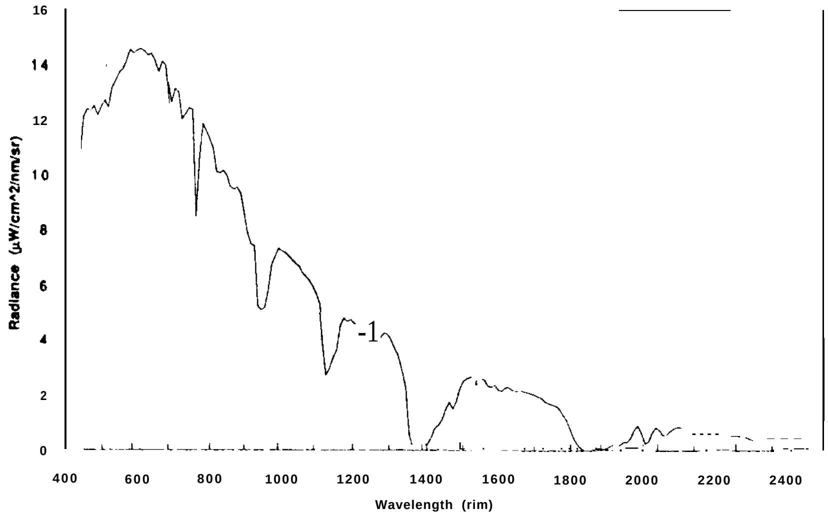

Figure 7. MODTRAN radiative transfer code predicted radiance for the calibration target.

4.0 INFLIGHT CALIBRATION ANALYSIS

To validate the calibration of AVIRIS while airborne in the ER-2, the AVIRIS measured and MODTRAN predicted upwelling spectral radiance spectra are inter compared and analyzed. Figure 8 shows the measured and predicted spectra plotted together.

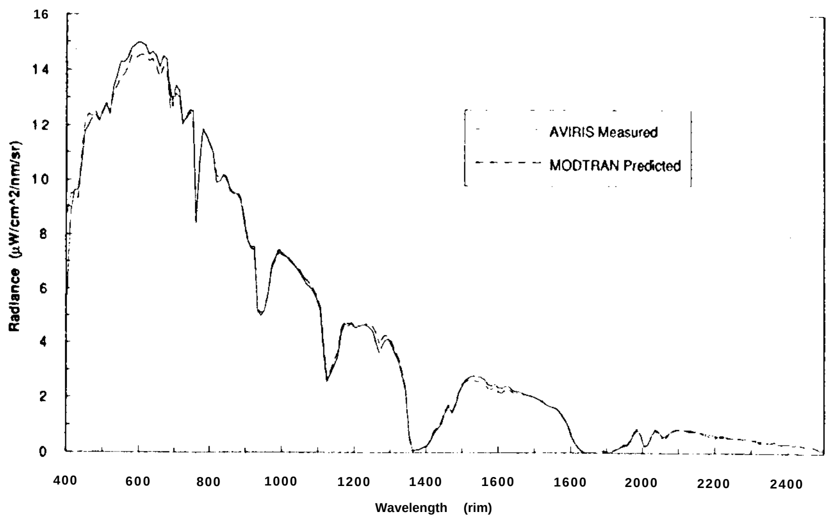

Figure 8. AVIRIS measured and MODTRAN predicted total spectral upwelling radiance for the calibration experiment.

4.1 Spectral Calibration

The known solar and terrestrial gas absorption lines present in the calibration experiment measured and predicted radiance spectra provide a basis for determining the accuracy of the AVIRIS spectral calibration in flight (Green et al., 1988; Green et al. 1990). A nonlinear least squares fitting algorithm has been used to determine the spectral channel positions that give best agreement between the measured and predicted spectra. For this experiment, the laboratory based spectral calibration agreed with the derived spectral calibration at better than 1 nm in the regions of the absorption bands spanning the AVIRIS spectral range.

4.2 Radiometric Calibration

Direct comparison of the measured and predicted upwelling radiance spectrum provides a basis for validating the radiometric calibration of AVIRIS in flight, The average absolute percent difference between the measured and predicted spectrum shown in Figure 8 is 4.7 percent, This value excludes the AVIRIS channels in the strong water vapor absorption bands at 1350 and 1850 nm where negligible energy is reaching the sensor. This residual disagreement of 4.7 percent may be attributed to errors in: (1) the AVIRIS sensor calibration, (2) the in situ measurements used to constrain MODTRAN, (3) the MODTRAN calculation of radiance, (4) the standard irradiance lamp and (5) the solar irradiance spectrum. Research is ongoing to establish the level of contribution of these sources to the residual discrepancy between the measured and predicted spectra at the calibration experiment.

4.3 Radiometric Precision

The inflight radiometric precision is determined by analyzing the AVIRIS radiance image and locating the region of greatest homogeneity on the lake bed surface. The standard deviation from this homogeneous region is assumed to result from the sensor noise. Figure 9 shows the standard deviation for a 5 by 5 spatial sample area adjacent to the calibration target on the Lunar Lake surface. This plot shows the worst case AVIRIS uncertainty due to sensor noise in units of radiance. The AVIRIS measured radiance signal for this 5 by 5 spatial sample area is given in Figure 10. The calculated signal to noise ratio is given in Figure 11. For this surface, AVIRIS shows a signal to noise of greater that 200 over most of the spectral range. To produce a result comparable through with previous determinations, this signal to noise is scaled to the AVIRIS reference radiance (Green, et al, 1988) and is shown in Figure 12. This plot shows AVIRIS to be exceeding the original signal to noise requirement of from 100 to 50 over the non absorbing region of spectrum.

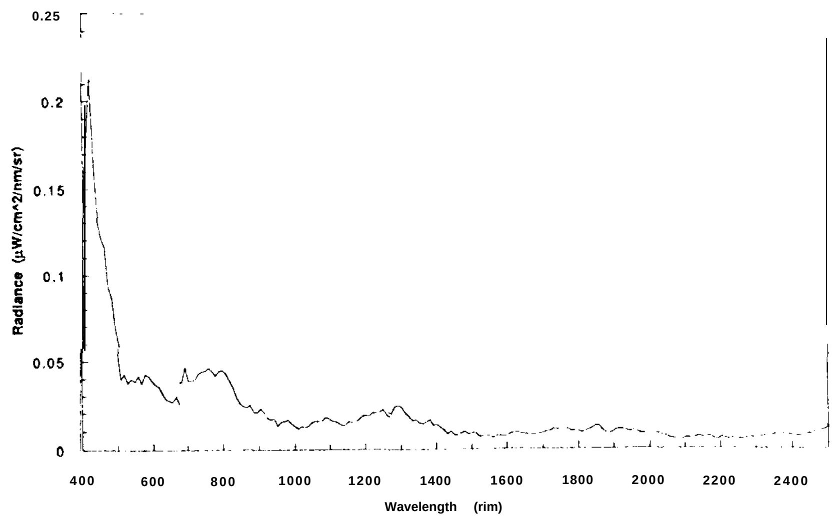

Figure 9. Inflight noise equivalent delta radiance.

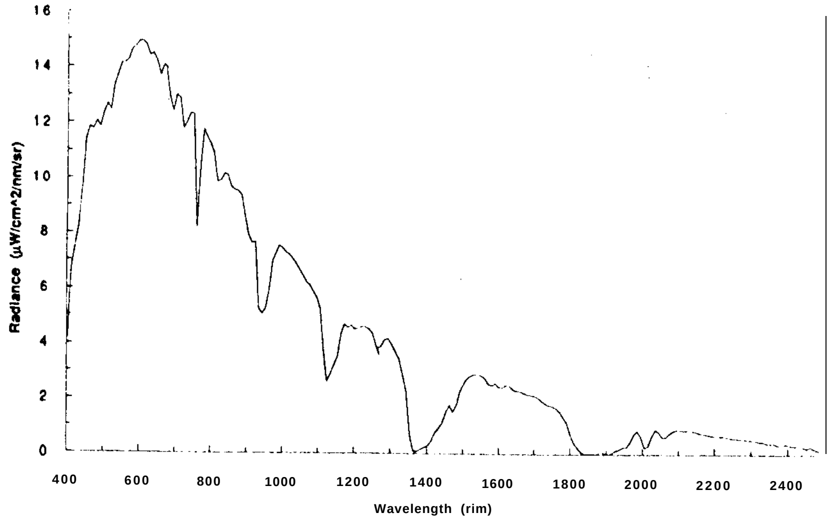

Figure 10. Radiance for the most homogeneous portion of the dry lake bed.

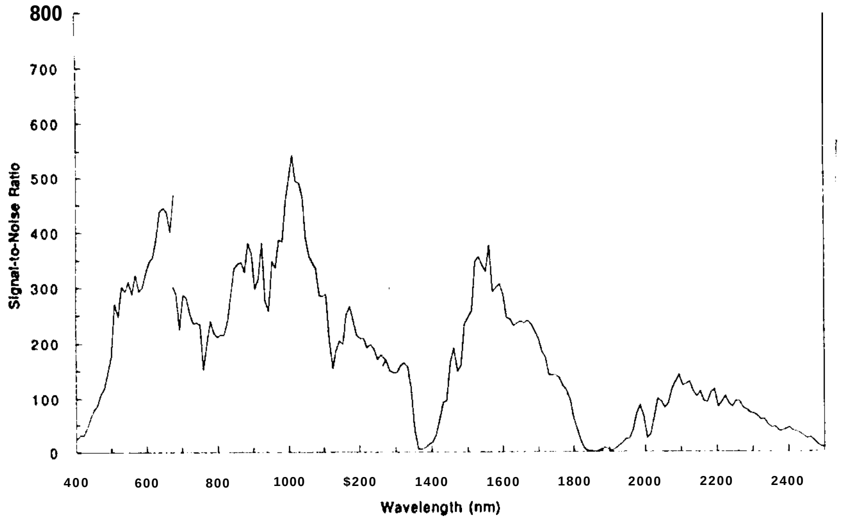

Figure 11. In flight signal to noise for the homogeneous portion of the dry lake bed.

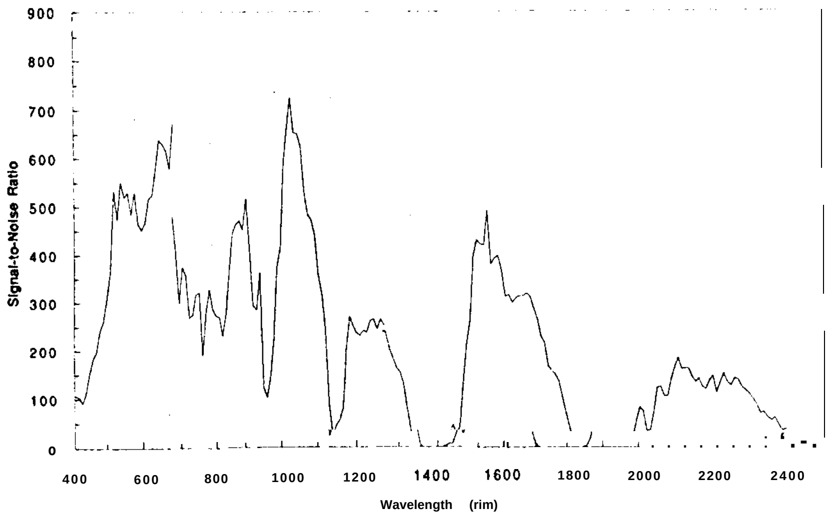

Figure 12. Signal to noise scaled to the AVIRIS reference radiance.

5.0 Summary

An inflight calibration experiment was conducted on the 26th of September 1993 at the dry lake bed surface of Lunar Lake, NV. In-situ measurements of the surface and atmosphere were acquired to constrain the MODTRAN radiative transfer code and predict the upwelling spectral radiance arriving at AVIRIS, while in flight. Analysis of this predicted and the AVIRIS measured spectrum of the calibration target showed the inflight spectral calibration to be accurate to better than 1 nm. The inflight radiometric agreement between the measured and predicted spectrum was at the 4.7 percent level excluding the effectively opaque regions of the atmosphere. Inflight radiometric precision and signal to noise ratio were determined from the homogeneous lake bed surface, The inflight this signal to noise is as high as 700 with values greater than 300 over much of the spectrum, This experiment shows AVIRIS to be calibrated in the flight environment of the Q-bay in the NASA ER-2 aircraft and appropriate for quantitative Earth science research.

5.0 ACKNOWLEDGMENTS

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